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THE TECHNOLOGY DEVELOPMENT STATUS OF THE SOLAR PROBE*

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Abstract

The continuing development of new spacecraft technologies promises to enable the Solar Probe to be the first mission to travel in the atmosphere or corona of the sun. The most significant technology challenge is the thermal shield that would protect the spacecraft from the flux of 3000 suns (400 W/cm **2) at the perihelion radius of 4 solar radii while allowing the spacecraft subsystems to operate at near room temperature. One of the key design issues of the shield is not simply surviving, but operating at temperatures well above 2000K while minimizing the sublimation from the shield surface. Excessive sublimation could cause interference with the plasma science experiments that are fundamental to the Solar Probe's scientific objectives of measuring the birth and development of the solar wind. The selection of a special type of carbon-carbon as the shield material seems assured at this time. Tests of this material in late 1996 were designed to confirm its optical surface properties and mass loss characteristics and the results are encouraging. The shield concept incorporates dual functions as a thermal shield and as a large high gain antenna. This latter function is important because of the difficult communications environment encountered within the solar corona. A high temperature feed concept under development is discussed here. The NASA guideline requiring non-nuclear power sources has introduced the requirement for alternative power sources. The current concept uses high temperature photovoltaic arrays as well as high energy, low mass batteries to provide power during the perihelion phase of the mission. Testing of photovoltaic cells at high sun angles was completed in 1996 and the results are presented here. Finally, a miniaturized science payload which relies on a the latest advances in analyzer and detector technologies will be developed to minimize mass and power requirements.

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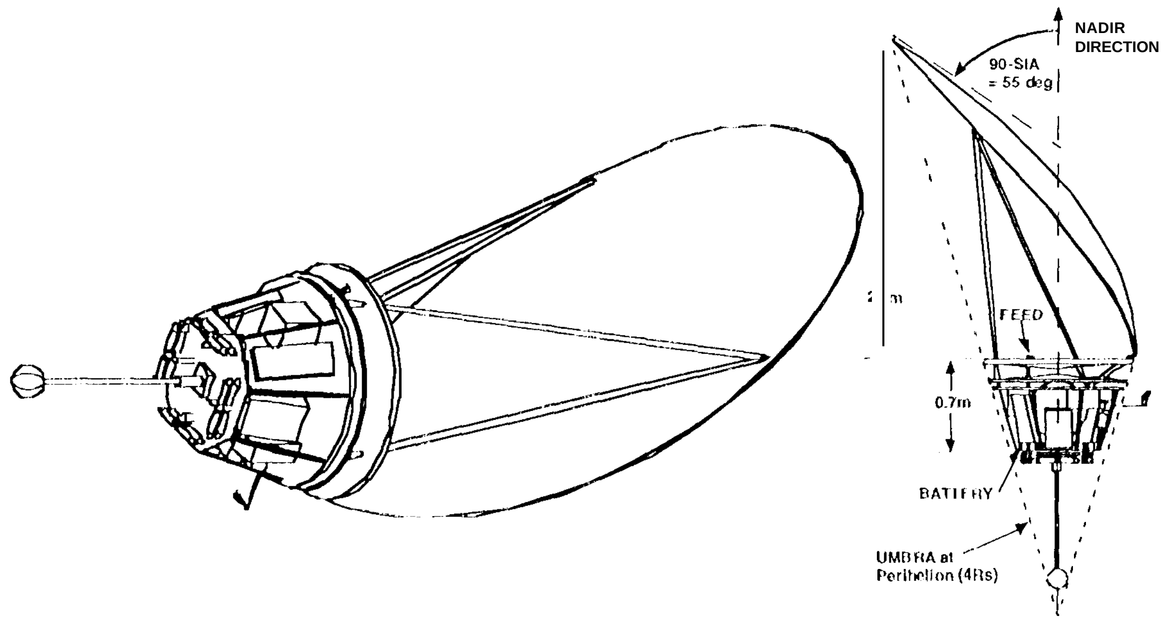
INTRODUCTION

A technology development program is underway for the Solar Probe mission as reported at the last STAIF meeting (Randolph, et al 1996). A new spacecraft design concept was also developed during 1996 in parallel with the technology activities. The spacecraft configuration is shown in Fig 1. Note the parabolic shield/antenna that is a key technology item. A new materials testing program was initiated with important new results affecting the design of the shield/antenna. New solar panel development tests have demonstrated their functionality at low illumination angles. A new development program promises to reduce a mass, volume, and power of the science instruments.



a. Isometric View

b. Side View

Figure 1 Solar Probe Spacecraft Configuration

HEAT SHIELD TECHNOLOGY DEVELOPMENT

A contract with Lockheed/Martin (Rawal, Jan 1996) was initiated to test some carbon-carbon coupons shown in Table 1 to determine their properties relating to the shield performance. The materials in the table were provided by NASA Langley Research Center (Vaughn, 1995) who has completed a series of mechanical tests on the materials. It can be seen from the table that many variations in manufacturing techniques were to be tested with these coupons. Of particular interest was the effect of the densification techniques on the optical properties at high temperatures. The phenolic densification evidently produces a more isotropic and less graphitic matrix resulting in a much finer grain structure in the material than does the pitch densification process.

Initial results (Taylor, 1996) suggest that certain Carbon Carbon samples have exceptionally high hemispherical emissivity (e) properties as shown by the curves labeled " Hemi e" in Fig 2. Note that the pitch densified material is the " Hemi e, 5 " curve of the figure. The pitch process evidently increases the emissivity as much as 20 percent over the other materials at temperatures above 1000K.

Table 1 Carbon-Carbon Test Coupon Descriptions

Coupon	Company	Fiber	Tow Size	Prepreg	Densification	Weave
1	C-CAT	P-100	2K	Phenolic	Phenolic	8HS
2	BFG #1	K-321	2K	hi-K	CVI	5HS
3	BFG #4	P-30X	2K	Phenolic	CVI	5 HS
4	BFG #5	K-321	4K	Phenolic	CVI	Tape
5	FMI	P-55	2K	Pitch	Pitch	8 HS
6	SAIC	"P-30011"1"	3K	Phenolic	CVI + Sealcoat	8 HS

A goal of the program was to demonstrate that the ratio of solar absorptivity to emissivity (a/e) could be less than one. Preliminary data from the tests (Rawal, Aug 1996) are shown in Fig 2 for the pitch densified coupon number 5 in Tab 1. The data are plotted as a function of solar incidence angle, SIA (0 degrees is a plane perpendicular to the sun line). Four curves are plotted for the a/e ratio for coupon number 5 ("a/e 5") at four different angles. The trends suggest that as the temperature increases the a/e ratio also increases in a non-linear manner shown in the figure.

The significance of these data can be related to the geometry of the configuration shown in Fig 1b. Note that the smallest SIA at the tip of the parabolic shield is about 35 degrees (90 - 55). Thus, the a/e value of interest lies below the "a/e 5, 30 degr" curve in Fig 2. It appears from these preliminary data that the a/e ratio will always be less than 1 for the range of expected temperatures (<2200K), even for this minimum angle near the tip of the shield. This value is less than what had been assumed (a/e = 1.1) in previous analyses (Randolph, 1994, Appendix B). In addition, as the SIA increases moving "down" the shield; the a/e ratio decreases significantly and the shield temperatures closer to the bus will be much lower than predicted by the previous analysis (ibid) which assumed a constant a/e ratio for all angles.

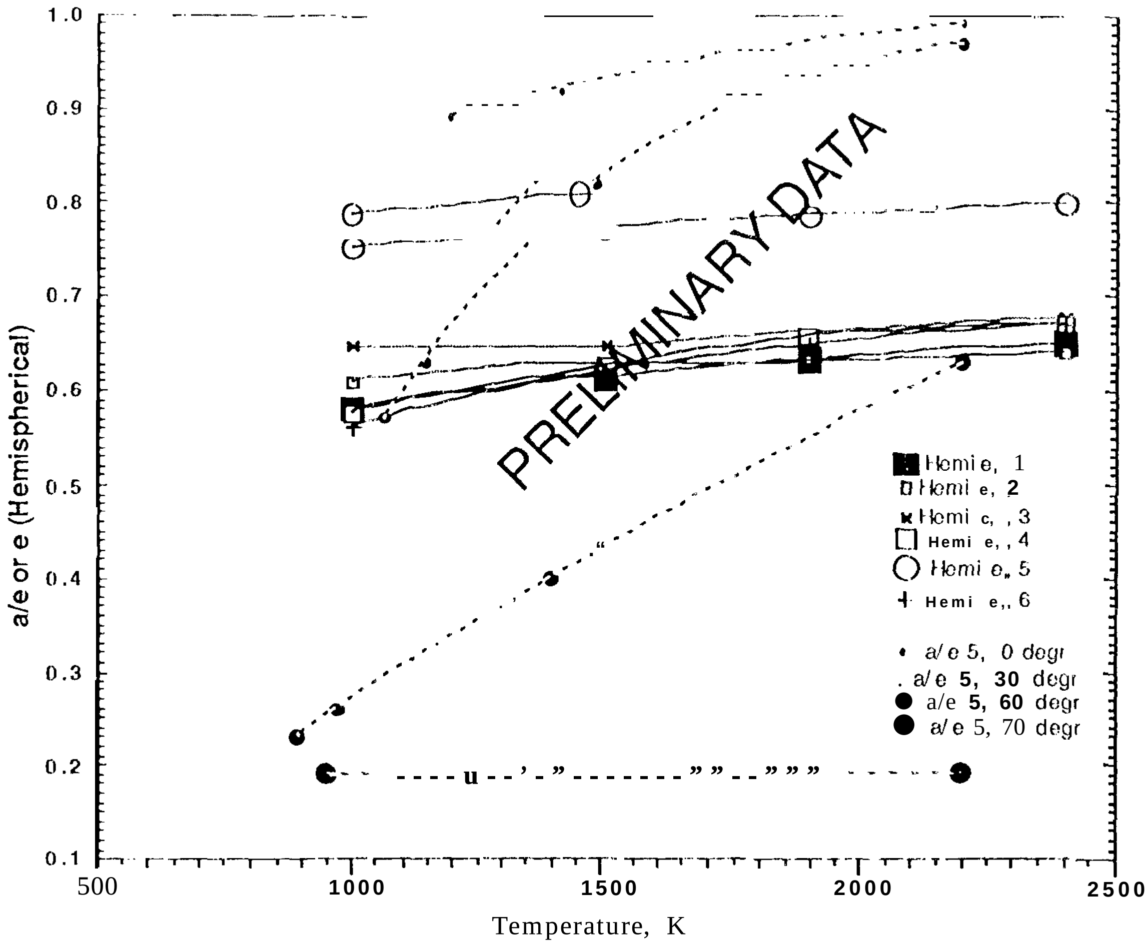


Figure 2 Thermal Optical Properties of Carbon-Carbon Coupons at High Temperatures

ANTENNA FEED DEVELOPMENT

Another development this year related to the antenna design was the initial concept for the antenna feed system that would operate at the high temperatures of the lower shield (1400K) at one end while the other end is connected to the transponder at room temperatures (300K). Fig 3 is a schematic drawing of the feed concept showing the cross dipole antenna enclosed in a cylindrical housing with a coaxial cable leading through the secondary shields and terminating in a waveguide which leads to the transponder. The high temperature dipole would be connected to the waveguide by a special high temperature coaxial cable. One of the technology issues is the development of this high temperature cable of some material that will be highly conductive but tolerant of high temperatures. The cable would pass through the two secondary (IR) shields as shown in the figure and connect to the waveguide such that the central lead of the cable protrudes into the waveguide cavity as shown in the figure thereby acting as a probe within the waveguide. With this arrangement and the thermal gap in the waveguide shown at the lower left of the figure, the 1400K temperature estimate at the feed is reduced to about 300K at the transponder.

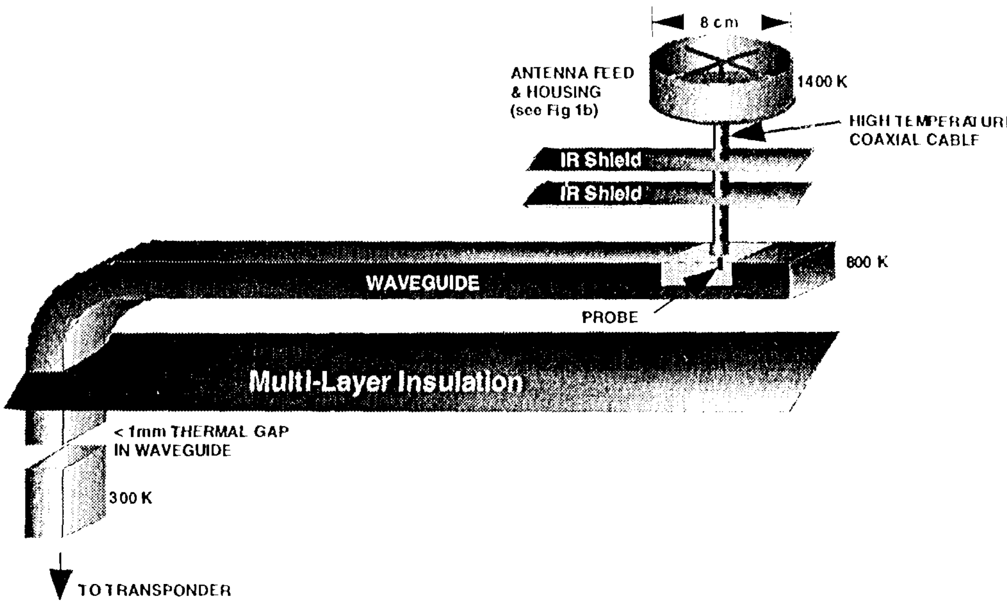


Figure 3 Schematic Diagram of High Temperature Antenna Feed System

SOLAR CELL TESTING PROGRAM

Another technology unique to the Solar Probe mission is the requirement for high temperature solar arrays to provide power as close to perihelion as possible (Randolph, 1995, pp.4 -29). A testing program was initiated at JPL in 1995 and was supported by Rockwell International (Burger, Mueller, Feb 1996). When an array gets close to the sun its plane must be aligned or "feathered" more and more closely to be nearly parallel with the spacecraft-sun line. If the solar incidence angle (SIA) is defined as zero when the plane is perpendicular to the sun line, then when the array is mar the sun it must be feathered to an SIA of almost 90 degrees to avoid overheating. The performance of the photovoltaic cells at these high angles must be understood to design the high temperature solar arrays. Several Ga As photovoltaic cell configurations were tested to determine their performance at large SIAs.

Some data from the testing is published here with permission from J. Preble of Rockwell International. Figure 4 is an example of the data (Burger, Mueller, 1996) from a cell with no cover glass. The plot illustrates the variation in relative power from the cell with high solar incidence angles. Both low (25°C) and high temperature (200°C) curves are shown. Some preliminary conclusions can be drawn from these data. Clearly, the high temperatures cause a significant reduction in power. However, that even at the extremely high SIAs shown in the figure, there is still a useable power output. The implication on the design of the high temperature solar arrays is that higher SIAS will be possible and high temperatures will be tolerable. This suggests that the high temperature arrays will be operational closer to the sun although these effects have not been factored into the design of the arrays at this time.

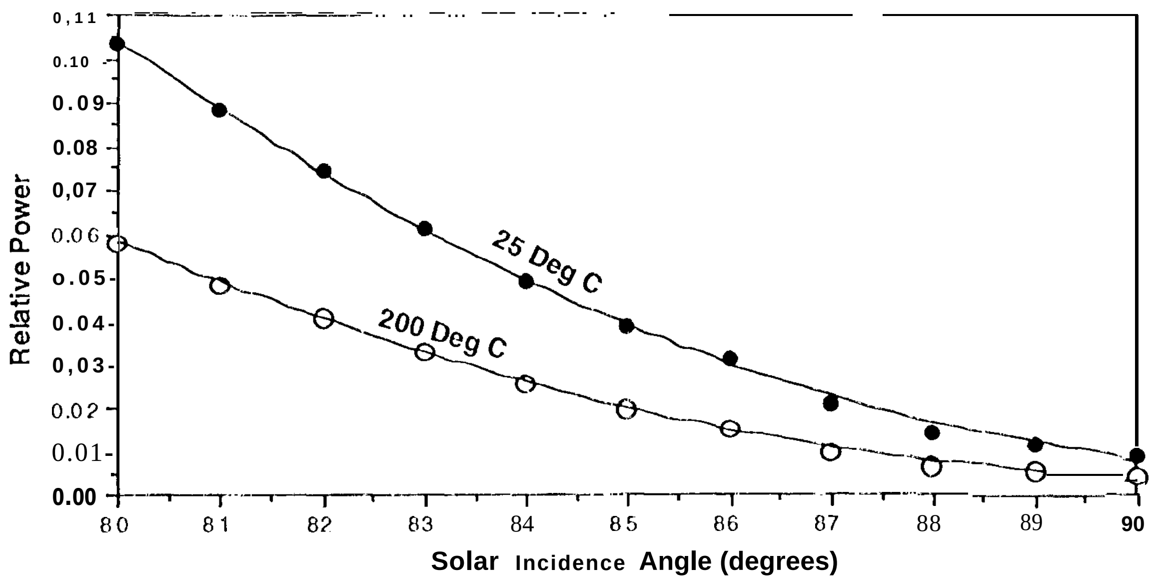


Figure 4 Solar Cell Testing Results

SOLAR PROBE INSTRUMENT DEVELOPMENT

A fundamental characteristic of the current Solar 1 'robe concept is the st nail size imposed b y the constraint of a small launch vehicle. The instruments, also, must be reduced in size to be consistent with this concept. in 1995, a NASA Research Announcement (NRA, 1995) was issued requesting proposals for the development of technologies that would lead to miniaturized instruments for the Solar Probe. In 1996, six proposals were selected for slutty. They consisted of two plasma instrument proposals (Sittler, 1996; Coplan 1 996), three imaging proposals (Title, 1996; Krieger, 1996; Korendyke, 1996), and one integrated instrument proposal (T. Tsurutani, 1 996). The goals of these proposals arc discussed below.

Proposed Plasma 1 nstrument Concepts

An ion and electron plasma instrument was proposed that incorporates a unique electrostatic mirror/shield/boom system (exposed to direct sunlight) to provide nadir viewing and a steering lens to allow viewing out of the orbit plane (3-D capability). It includes top-hat analyzers using a common collimator for the ion and electron spectrometers along with a time-of-flight section.

The other plasma instrument concept to be developed also employs a top-hat analyzer configuration. It incorporates a gated time-of flight technique for ion (e.g. H, HE, 0) composition determination with an Ii/q range from 10 eV to 6000 eV. The electron analyzer will be designed to provide data such that a 3-1) distribution function for electrons Over tile energy range of 5 eV to 3000 eV can be const rutted every 1(1 seconds.

Proposed 1 maging Inst rument Concepts

A state-of-the-art, light weight, high resolution soft X-ray telescope concept was selected for development. It will be designed to obtain images of the lowest levels in the corona at hi gh spatial resolution (angular resolution of better than 2..3 seconds of arc at 10 solar radii). The concept employs grazing incidence mirrors and X-ray sensitive CCDs.

Also selected was a concept that would use two separate coronagraphs to provide panoramic and high resolution images of the white light corona, to study its global and fine scale structure. The panoramic coronagraph will be designed to have a field of view from within a few degrees of the heat shield out to about 160 degrees from the spacecraft-Sun line.

The third imaging concept selected would integrate several instruments: a visible light magnetograph, an XUV imager for observing the solar surface, and a wide angle coronal imager (white light coronagraph). The visible magnetograph will image the Fe I 6302 Å line with spatial resolution of 37.5 km/pixel over the solar poles (at 8 solar radii). The XUV imager would be aligned with the magnetograph and would be tunable; operating in the spectral region from 170 to 220 Å with a spectra resolution of 4 Å. The coronal imager concept is essentially a fisheye camera designed for a field of view of approximately 100 degrees and imaging at all azimuths.

Proposed Integrated Sensor System Concept

One proposal was selected for the investigation of an integrated sensor "system" concept. It implements a novel electrical architecture with dedicated sensor preprocessors. Its plasma instrument will be designed to measure 3-D plasma distribution functions, plasma waves, and magnetic fields. This concept will also incorporate a visible magnetograph, EUV imager, coronagraph, and energetic particle sensor. Key to this concept is the development of the central processor and the data handling architecture necessary to interface with, and process, the multiple sensor output.

CONCLUSIONS

The results Of technology development activities for the Solar Probe in 1996 are very encouraging. The carbon-carbon test results confirm that the current shield design is good and that a reasonable *design margin* exists in the optical properties of the material. Additional data regarding the sublimation rate of carbon-carbon as a function of manufacturing processes will be obtained in 1997. A new concept for the antenna feed system confirms that if a high temperature coaxial cable can be developed, then the feed system can be implemented with no other technology issues. The solar cell testing completed in 1996 suggests that the high temperature solar arrays can be taken to a distance closer to the sun than in the current mission concept. Although the instrument development for the Solar Probe is only beginning, the proposals received suggest that the new innovative techniques will significantly reduce the complexity and mass of the payload from previous estimates. At this time the work has only begun and first results are expected in 1997.

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